PRELIMINARY DESIGN OF A FAST RISE, FULL THREAT LIGHTNING SIMULATOR

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ABSTRACT

There is increasing evidence that the risetime of a lightning flash high current return stroke is a factor of ten faster than what has been generally accepted. This new information can affect established lightning simulation parameters and the equipment used to generate the waveshape for simulation testing. This paper is a design exercise for a generator capable of a 0.1 μs risetime pulse with a peak current magnitude of 100 kiloamperes. The generator is intended to be used for aircraft susceptibility testing to lightning effects. As such, the test circuit includes the resistance and inductance of the aircraft under test with the current return path to complete the circuit.

INTRODUCTION

The Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories is the Air Force focal point for research into lightning effects on aerospace vehicles. One prime concern is induced voltages and currents on internal sensitive electronics of modern aircraft systems. Figure 1 shows a typical lightning strike following a wingtip to wingtip path through the aircraft. As the current propagates, associated electromagnetic fields couple to the aircraft internal wiring and systems. The magnitude of the magnetically coupled induced effects is related to the rate of flux change through aircraft apertures, and is therefore dependent on the risetime of the current stimulus.

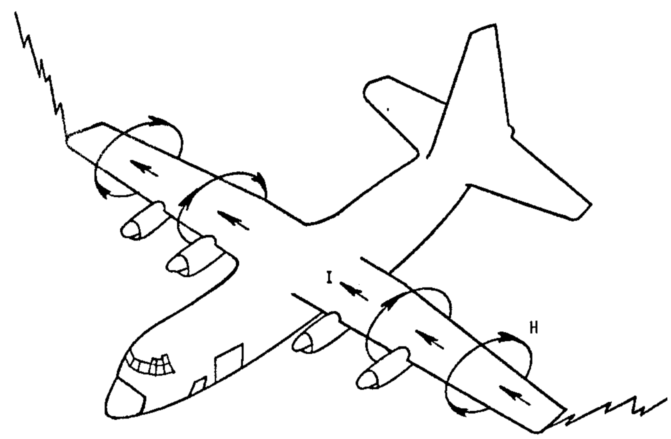

Figure 1. Diagram of Lightning Effect on Wingtip to Wingtip Strike.

Recent observations of the threat presented by lightning to aircraft using modern wide bandwidth instrumentation have recorded considerably faster risetimes of the electric and magnetic fields than the previously accepted standard of two microseconds.[1,2] These newly measured risetimes, also observed in ground-based measurements, are predominantly in the 100-200 nanosecond range[3,4] and have been measured as fast as 30 nanoseconds.[5] The evident faster risetime increases the severity of the lightning induced threat to aircraft electronics.[6] However, the ability to apply this increased threat to an aircraft is beyond the capability of present generators and simulators.

The state-of-the-art for a lightning current injection test is exemplified by the concept utilized in 1979 to subject an F-16 aircraft to the then standard pulse waveform. A two-stage, high current Marx-type capacitor bank is discharged through the aircraft back to the bank to result in a unipolar pulse of 30,000 amps peak magnitude (a median amplitude lightning stroke). In order to achieve the then acceptable 2 microsecond risetime, aluminum sheeting deployed along the aircraft

Report Documentation Page			Form Approved OMB No. 0704-0188

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1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUN 1981	**N/A**	-

4. TITLE AND SUBTITLE	
Preliminary Design Of A Fast Rise, Full Threat Lightning Simulator	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Wright Aeronautical Laboratories Wright-Patterson AFB OH 45433**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

at a separation of one fuselage radius was used for the return path to minimize the circuit inductance, as described by Burrows.[7] This configuration, shown in Figure 2, could reduce the aircraft/return path contribution to the circuit inductance to the 3-4 μh range for fighter size aircraft. At this minimum inductance value, the new, faster risetime threat presents simulation equipment design problems. A conventional capacitor current bank (one or two stage Marx with output voltage = 200,000 V or less) cannot develop the desired output performance called for in this inductance limited test technique.

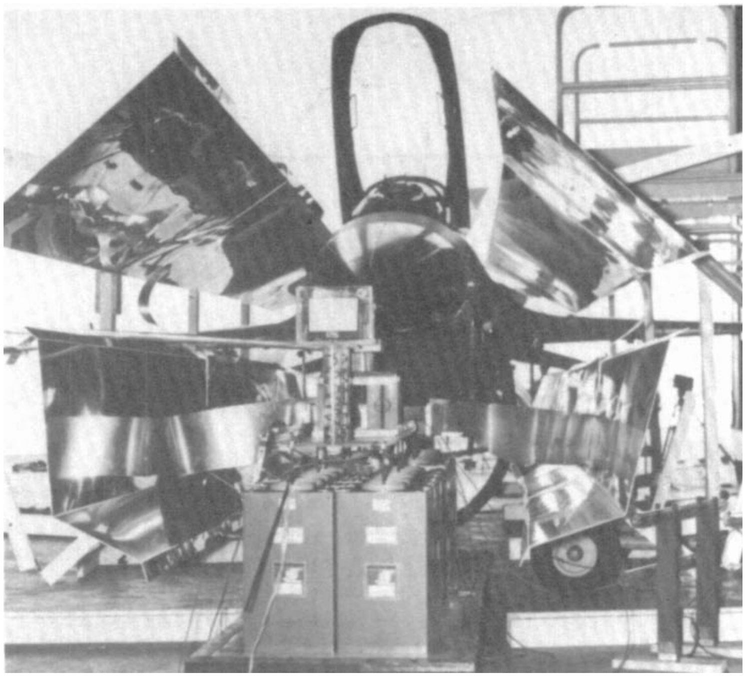

Figure 2. Actual Test Setup on F-16 Aircraft.

CONCEPTUAL DEVELOPMENT

One method to theoretically obtain the desired test input threat parameters is to couple a high voltage Marx generator to a peaking circuit used to sharpen the output pulse leading edge. The two potential sharpening circuits considered for this paper were a peaking capacitor and a fusible inductive store. Since the Marx generator voltage would be on the order of megavolts, the peaking capacitor option was discarded due to constraints associated with the very large physical size required for energy storage. The inductive store concept, having the higher energy density capability, would correspond to a generator having a small, more practical volume. In addition, the general fusing technique necessary for the implementation of a fast risetime, inductive store generator has been demonstrated by similar devices.[8, 9]

The required design parameters for such a generator system were obtained via iterative computer calculations and simulations of the general circuit shown in Figure 3. Potential solutions were correlated with limitations imposed by existing state-of-the-art components. In this way a feasible configuration was eventually obtained from the computational program.

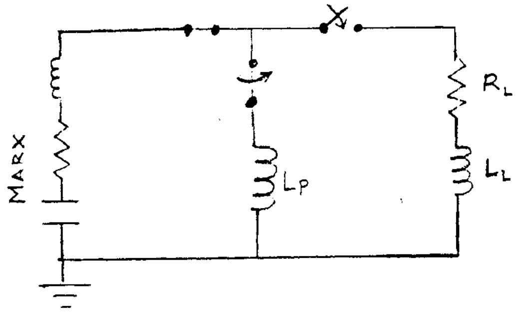

Figure 3. Schematic of Simulation Circuit.

The subject test aircraft and its return path were modeled as a two Ω, seven μh load (R_L and L_L). These values are considered realistic and should be easily attainable with fighter size aircraft, even if the higher voltage levels prevent optimized use of the low inductance return paths. The output was required to simulate the lightning threat waveform of 100 KA with a 200 ns risetime, which was recently (Dec 79) adopted by the MX Missile Systems Program Office. It quickly became evident that the risetime was the most difficult requirement, demanding that inductance in the circuit be minimized. For this reason, an S-type Marx configuration was chosen using the highest energy density, low inductance capacitors presently available. The S-type Marx results in a configuration that has two capacitors connected in series per stage, charged ± half the stage voltage. Therefore, the 6 μf @ 60 KV capacitors yield a stage voltage of 120 KV. To further minimize inductance, the Marx generator uses rail type spark gaps (≈ 10 nh) and current path bus bars that are tubular in shape as well as of relatively large diameter (15 cm). Oil immersion of the Marx system decreased required standoff distances, reducing total size and electrical length, another input into internal inductance.

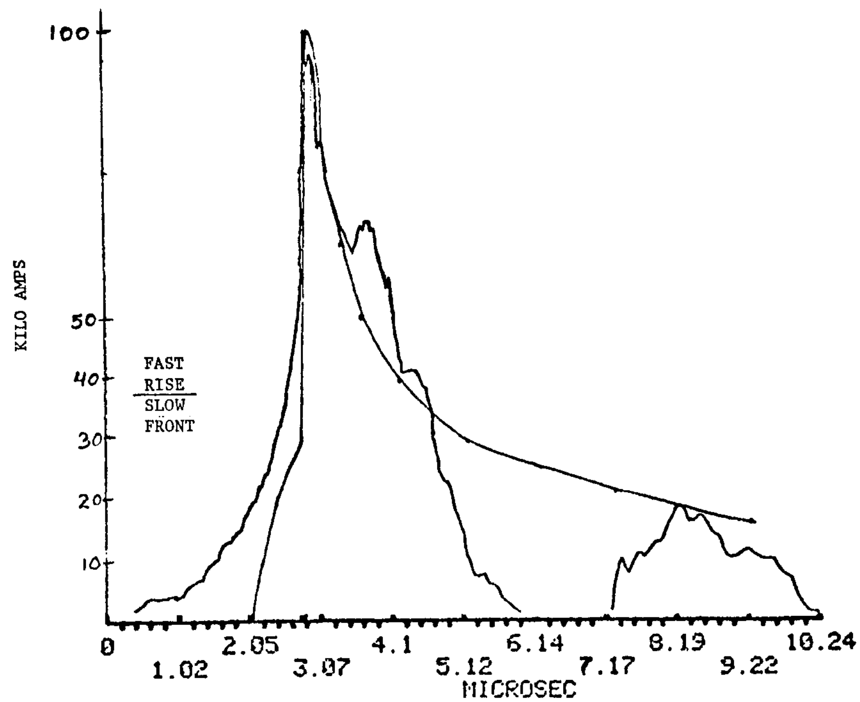

Figure 4. Comparison of Simulator Output With Scaled Up Lightning.

The computer simulation uses the Runge-Kutta integration method to determine component parameters with respect to time, with three different circuit configuration phases. In phase 1, the Marx begins its discharge through the inductive store (L_p) with the output switch to the load (spark gap) open. When a predetermined current is attained in the store, the output gap is triggered, starting current to the load. This configuration is phase 2. Phase 3 begins when the fuse to the store interrupts directing the total current through the load. Iteration of initial design values converged to a feasible system of 15 stages for the S-type Marx (1.8 million volts). The computed output pulse to the load is shown in Figure 4, where it is compared to a scaled up representative lightning waveform. This output appears to be a good simulation of the first stroke (initial amplitude peak) with a "slow front" followed by a "fast rise." An additional benefit of this technique is that the "slow front" can be modified by varying the switch gap timing and relative peaking circuit parameters to the point of its virtual elimination, thereby simulating a subsequent stroke (or restrike of the flash) which does not exhibit the "slow front" behavior.

To illustrate the importance of the inductive store/fast opening switch technique, a simulation was performed using a Marx generator with the same design values discharged directly into the load without the peaking store. The result was a double exponential waveform of 51 KA peak with a 480 ns risetime (10%-90% points).

Although the system appears feasible, there is some engineering development required of hardware components. Basically remaining problems concern the 1.8 million volt operating voltage. This poses physical configuration problems associated with control of flashover and corona; it also exacerbates the necessary switch requirements. The fast closing output switch may require many triggered spark gaps in series and yet isolated from ground to withstand the voltage level. This environment and the need for precise switch timing with jitter control into the nanosecond regime may require laser triggering of the closing gaps. The fast opening switch of the peaking circuit may prove to be a more difficult problem. The computer simulation modeled the switch operation as a complete and instantaneous current interruption between computer stepwise iterations (10 ns). In actuality, this process is far from linear or even repeatable, and current quenching within 100 ns is required to achieve the desired system performance. The SHIVA has accomplished 100 ns quench with a fusible

foil, but interruption at the proposed current and voltage levels has not been demonstrated.

FURTHER WORK

Since the computer simulation used a rather simplistic switching model, further studies should be performed with a more sophisticated and practical switch model. The opening switch parameters should be modeled to vary with time as demonstrated on other devices using fusible current interruption techniques.

Experiments should be conducted to identify engineering problems concerning the opening switch fuse and to verify that the necessary performance can be achieved as the voltage/current levels intensify.

The need for a worst case test capability should be reevaluated. The 100 KA amplitude is a representative 99 percentile lightning strike. To obtain the capability for the remaining one percent of strikes (200 KA) requires doubling the generator voltage level and thus the number of stages, greatly increasing implementation problems, complexity, and cost.

In summation, this design offers an alternative to other proposals for fast risetime lightning simulation, and appears to have potentially significant operating and construction cost advantages.

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